https://doi.org/10.14669/AM/157645

DRIVER'S DISTRACTION AND ITS POTENTIAL INFLUENCE ON THE EXTENSION OF REACTION TIME

SŁAWOMIR TARKOWSKI[1], JACEK CABAN[2], MARIUSZ DZIEŃKOWSKI[3], ALEKSANDER NIEOCZYM[4], JANUSZ ZARAJCZYK[5]

Abstract

The driver's reaction time is one of the most important parameters for the road pre-accident analysis. There are known the results of tests, in which the value of this parameter was determined in expected and unexpected road situations. But in some cases, this time may be longer e.g. in situations in which the driver's attention may be distracted by keeping observations other than the area, in front of the car's surroundings. There are many manoeuvres, when the driver is obliged to observe many areas at the same time. Thus, his attention must be turned away from the main area – in front of the vehicle. The paper presents the results of tests involving the measurement of the driver's attention time focused on observing the surrounding other than the car's path. During the test, the driver's attention was focus on observing the side and back mirror, car radio and at the mobile phone. Certain values can be potentially considered as extending the typical driver's reaction time. The results of the presented tests have practical applications and can be used in the process of issuing opinions on traffic accidents.

Keywords: traffic safety; driver's attention; reaction time; eye tracking

[1] Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 38D, 20 – 618 Lublin, Poland, e-mail: s.tarkowski@pollub.pl, ORCID: 0000-0002-2110-7136

[2] Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 38D, 20 – 618 Lublin, Poland, e-mail: j.caban@pollub.pl, ORCID: 0000-0002-7546-8703

[3] Faculty of Electrical Engineering and Computer Science, Lublin University of Technology, Nadbystrzycka 38D, 20 – 618 Lublin, Poland, e-mail: m.dzienkowski@pollub.pl, ORCID: 0000-0002-1932-297X

[4] Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 38D, 20 – 618 Lublin, Poland, e-mail: a.nieoczym@pollub.pl

[5] Faculty of Production Engineering, University of Life Sciences in Lublin, Gleboka 28, 20-612 Lublin, Poland, e-mail: janusz.zarajczyk@pollub.pl, ORCID: 0000-0001-5954-6575

https://doi.org/10.14669/AM/157645

1. Introduction

Road accidents entail great social and economic losses for countries, families and individuals [10]. Road safety is one of the most important elements of the transport sector. In the literature, the issue of transport safety is widely described and covers many aspects. There are studies on accident statistics [10, 27, 28], vehicle safety design [23, 36], vehicle safety systems [5, 8, 14], transport infrastructure [11, 24, 44], traffic flow [2, 20, 21], driving techniques [30, 37, 40], issues related to transport psychology [22, 26], legislative issues [1, 7, 33] or transport safety management systems [17, 35, 38].

Many factors affect the level of safety in transport. They can be classified into three basic groups related to: the human factor, factors dependent on means of transport, and those related to the transport environment. They form the so-called the safety chain, which is marked as H-V-E (human - vehicle - environment). Each of these groups is important and plays a significant role in ensuring a high level of security. The weakest and at the same time the only intelligent link in this chain is man. However, it cannot be overlooked that some elements of the broadly understood transport environment and (paradoxically) selected legal regulations may reduce this level. They cause an excessive burden on the attention of the drivers and distract them, which may extend the reaction time to the threat. Research using, among others, the Monte-Carlo method, concerning the driver's reaction time in the context of a road accident, was presented by Guzek [15]. In these studies, a driving simulator was used and real road tests were carried out on the test track for selected states, such as emergency braking and obstacle avoidance. Issues related to the braking manoeuvres of various vehicles are the subject of many studies [9, 31, 34]. Erd et al. [9] presented research on the braking of passenger cars in various road conditions. Similar studies were conducted by Gosławski and his team [12]. Rievaj et al. [34] and Orynych et al. [31] additionally considered the influence of vehicle tire pressure during emergency braking tests. Other studies on driver distraction were presented by Hudak and Madlenak [16, 25], who analysed the impact of the road environment on the distraction of the driver's attention and determined the time the driver's attention was focused on roadside advertisements.

The article presents the results of experimental research involving the measurement of the time the driver's attention is focused on observing areas other than the car's track. During the test, the driver's attention was focused on the following areas: the side and rear mirrors, the car radio and the mobile phone. Certain values can potentially be considered as increasing the reaction time for a typical driver. The obtained research results can be helpful in the assessment of road incidents and reconstruction of accidents and other issues related to road safety.

2. Reaction time and its influence on the level of security

Reaction time is the period that elapses from the occurrence of a factor that can be objectively recognized as the beginning of a situation threatening safety (the so-called beginning of a state of emergency) to the moment when the driver starts defensive manoeuvres.

https://doi.org/10.14669/AM/157645

Tests of the reaction time of drivers of the type are performed in laboratories on a driving simulator or during road tests. As a supplement, psychophysical tests are carried out to determine individual human characteristics and their impact on driving behaviour.

The results of tests in three research environments of accident hazard situations involving pedestrians and passenger cars entering the road area were published in [18, 19]. The scenario assumed the possibility of pedestrians from both the left and right side of the road. The paper analyses the values of the driver's reaction times characteristic of the driver's influence on: accelerator control pedals, the main brake and the steering wheel. In addition to determining the average values of the reaction time, the frequency of individual defensive reactions by drivers was assessed.

The results of similar experiments are presented in [32]. In this case, the relationship between the speed of driving a car and the execution of an immediate defensive manoeuvres in response to dangerous events was checked. Drivers participated in a simulation study of the impact of time pressure for two different situations: pedestrian intrusion into the crossing and avoiding obstacles. The time pressure was defined by the distance of the vehicle from the obstacle at the time it was shown on the simulator screen.

The combination of the laboratory method with a road test to determine the reaction time of drivers in real road conditions is presented in the literature [6]. The driver had to react to a complex signal in the form of lights of different colours by performing a braking manoeuvre. The study measured the perception time and the time it took to move the leg from the accelerator to the brake pedal. The possibility of extending the time of each test and the possibility of extending the stimulus by adding more lamps or a sound signal are described. Such changes are intended to eliminate the driver's schematic reaction to the emerging signal and will allow the recording and analysis of individual reactions.

Activities not related to driving and which affect the speed of decision-making are also assessed. A comparative analysis of reaction time was performed to assess the negative impact of talking on the phone [46]. The combined reaction time of a vehicle driver talking on a mobile phone increases by approximately 20%. This is the result of an additional attention burden and mental involvement in conducting a conversation. It also changes his ability to see and understand the situation.

A certain group of studies aims to answer whether there is a correlation between the age of the driver and the reaction time to road hazards. In [39], a study of drivers aged 20 to 80 was written in terms of reaction time while driving. Drivers performed a full stop manoeuvres on a given signal and then were distracted before the signal for a stop manoeuvres was triggered. Reaction times were compared across different conditions and age groups. The data clearly supported the claim that driving ability as well as average reaction time varies steadily across age groups – gradually increasing with age. These results are not always confirmed in research, for example in [6] it was shown that there is no correlation between the age of the driver and the total reaction time. In addition, as the author of the article [39] writes, a significant group of older drivers was identified who did not show the expected age-related decline in fitness.

https://doi.org/10.14669/AM/157645

The problem of driving under the influence of alcohol is extremely important and current. A drunk driver has a reduced ability to see obstacles due to the so-called tunnel vision effect. In this way, he loses the ability to see peripherally, which may lead to the inability to react to a moving obstacle [3]. In the experiment described in [43], the driver's reaction time after drinking a dose of alcohol was monitored by measuring the time from two synchronized cameras. The driver was tasked with stopping the vehicle (and thus reacting) to the simulated stimulus. Auxiliary variables were also recorded during the braking distance and braking deceleration tests. The most important variable was driver reaction time. This was investigated using video analysis from two synchronized cameras. One camera was placed on the windshield to monitor the situation in front of the vehicle, the other monitored the movement of the driver's feet.

Driver reaction time is the most important factor contributing to road accidents. The reaction time depends on several factors, such as the psychophysical condition of the driver, the technical condition of the vehicle, the condition of the road infrastructure. While driving, the driver's perception and cognitive factors, visibility, reaction to reflections, driver's adaptation to darkness and road illusions are involved [4]. The driver's reaction time also depends to a large extent on the type of situation, obstacles on the road and the speed of the vehicle.

The literature presents an attempt to compare the reaction time values obtained in laboratory and road conditions and to determine the correlation between them. The reaction time of the drivers obtained in the simulator for all the tested manoeuvres reaches lower values in relation to the values measured on the track. The reason is that drivers are aware that they are driving a car in a virtual environment, so they even decide to make very violent manoeuvres. During the test on the track, drivers behave in such a way as not to lead to a dangerous situation, e.g. a car overturning [18, 19].

Regularity in changes in the reaction time of drivers was observed, both in laboratory and field conditions. The results obtained in real conditions show that the reaction time of drivers is on average twice as long as in laboratory conditions. This is partly due to the fact that in the laboratory it is possible to eliminate the influence of external factors on the driver's reaction time. The differences in the results between the measurements carried out in the laboratory and in real conditions were: in the first age group (20–35 years) – 83%, in the second (35–50 years) – 4%, and in the third (over 50 years) by 112% [45].

Discussions also arise in the estimation of time differences obtained by the above-mentioned two methods. According to [13], the reaction times on the track are 0.3 s longer for braking, and in [29] it is stated that the reaction times on the track are 0.1 s longer when braking and 0.03 s longer when turning. The studies presented in [19] show that this difference is not constant, but varies depending on the time of risk characterizing a given sample.

You also need to be aware that the behaviour of drivers during each sequence of manoeuvres in the simulation or road test has been determined for a specific scenario of the pre-accident situation. For other scenarios, the driver behaviour situation may be different. There-

https://doi.org/10.14669/AM/157645

fore, further research should consist in determining the impact of various scenarios on the obtained reaction time of drivers [18, 19].

The driver's reaction time is important for both the performance of a defensive manoeuvres and for the possible analysis of an accident or road collision. At the same time, this value in seconds cannot be precisely determined. Each event is characterized by a number of individual actions, which in the case of reaction time are variable and individual for each driver. In the reconstruction of road incidents, the average values were determined for situations with similar parameters. The methods used to determine a specific reaction time differ in accuracy and the way of presenting driving conditions, so it is impossible to clearly determine which of them is the most appropriate [6].

The lack of correlation between the results of the experiment on the track and in the simulator means that the reaction time obtained in laboratory tests cannot be treated as the real reaction time of drivers in road situations and cannot be used in the reconstruction of road accidents. This conclusion is very important because in some publications the reaction time determined in similar positions is taken as the actual reaction time of drivers in the accident analysis [19]. The results of the tests [13, 29, 41] also do not cover situations in which the driver's attention may be distracted due to the duties imposed on him or activities not related to driving, performed while driving.

3. Factors potentially affecting the extension of reaction time

Many activities performed by the driver while driving force him to be distracted and focus on an area other than the one directly in front of the vehicle. In some cases, the driver is "required" to focus his attention on several areas at once. This can occur, for example, during a change of direction, lane change or overtaking. Observing many areas at the same time is beyond the capabilities of the human body, even taking into account the width of the field of view and the so-called peripheral vision.

It also happens that while driving, the driver performs activities other than those resulting from the rules of the road, which cause distraction. These can include checking the speedometer readings, looking at the car radio or navigation system. You can also meet people who use mobile phones while driving.

In each of the above-mentioned cases, the driver's attention is focused on the currently performed activity, which means that if the threat occurs in an area other than the currently observed one, the reaction to it may be delayed.

https://doi.org/10.14669/AM/157645

4. Driver distraction time test

In order to determine the value of the time necessary for the recognition and interpretation of the situation by the driver, experimental studies were carried out in various areas. They assume that the "basic" task of the driver is to observe the surroundings in front of the vehicle. During the tests, it was the subject's responsibility to observe the surroundings through the windshield (main area) and to perform activities requiring temporary focus of attention and shifting the gaze beyond this area. The way in which the examined person conducted the observation was determined on the basis of the analysis of the temporary position of the eyeball. In order to monitor it, the SMI Eye tracker system was used, which consisted of glasses equipped with a camera system, a clock indicating time with an accuracy of 0.01 s and a video recording device. The temporary position of the eyeball during the examination was marked by the system with an indicator (Figure 1). The recorded video record was subjected to analysis, during which the total time elapsed from the pointer's movement outside the windscreen area to another area to its return to the "main" observation area was determined. The value thus determined is referred to as 'driver distraction time'.

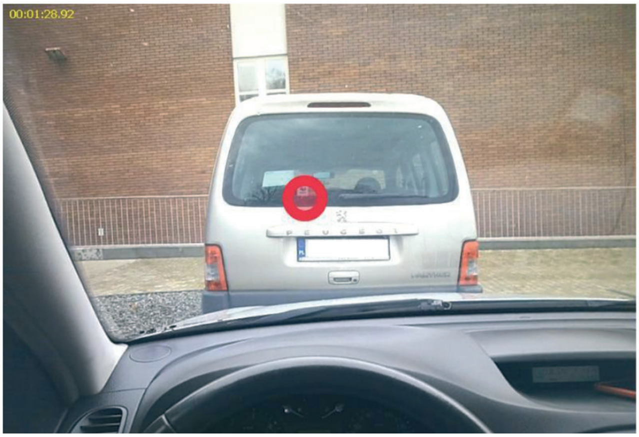

Fig. 1. Frame of video recorded by the SMI Eye tracker system

The research was divided into two stages. In the first stage, the measurements were carried out using the static method, while the vehicle was parked in the parking lot. In the second stage, the measurements were carried out while the vehicle was in motion.

4.1. Static tests and their results

During the static tests, the driver's distraction time was analysed for the following observation activities:

- look in the left mirror,
- looking in the rear-view mirror,

https://doi.org/10.14669/AM/157645

- checking the current time on a mobile phone,
- a look at the car radio combined with changing the radio station,
- preparation for the manoeuvres to change the direction of movement to the left (according to the requirements specified in [42].

The research group consists of 10 people aged 22–24 (three women and seven men). Each of them had a category B driving license. One of the men had a visual impairment and used contact lenses during the examination – just like when driving a car. The remaining persons had no vision defects and did not use corrective glasses or contact lenses. Each of the subjects in random order performed the planned observation activities (i). The sequence of these activities was determined by the person supervising the tests, who was inside the vehicle. The measured time was written with the symbols $t_1 \div t_{10}$. Based on the measured values, the mean time t_m and the standard deviation σ_t were calculated. The times t_{i1}, t_{i2}, t_{i3} are times determined during the study of women. The remaining times were determined for a group of men. The test results are presented in Table 1.

Tab. 1. Static test results

Action	Time t [s]											
	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_m	σ_t
Looking in the left side mirror (LM)	1.83	1.67	1.72	1.51	1.59	1.67	1.03	1.39	0.99	1.80	**1.52**	0.28
Looking in the rear side mirror (RM)	1.38	2.05	2.21	1.31	1.26	2.00	1.13	1.48	1.43	1.25	**1.55**	0.37
Checking the current time on a mobile phone (K)	3.09	3.00	3.19	2.71	5.88	2.05	X	3.55	4.32	4.17	**3.55**	1.05
Changing the radio station (R)	1. 17	1.58	1.88	2.25	4.42	2.33	0.96	2.30	1.58	1.67	**2.01**	0.91
Time of (distraction) distraction associated with turning left (SL) t_{sl}	4.34	2.63	4.79	3.25	3.30	2.60	1.42	1.30	3.17	2.67	**2.95**	1.05

In the case of the scenario involving the performance of observation activities related to the manoeuvres to change direction to the left, the measured time of distraction from the field in front of the vehicle was in the range of $t_S = (1.30–4.79)$ s. During the analysis of the recorded video material, it was observed that in one of the cases the eyesight of the examined person was not focused solely on observing a specific area. There was a phenomenon that can be described as “eye wandering” manifested by repeated shifting of the gaze to the observed area and the area in front of the vehicle. This phenomenon was observed while observing a mobile phone and concerned person “7”. The average value of observation time by women and men is shown in Figure 2.

https://doi.org/10.14669/AM/157645

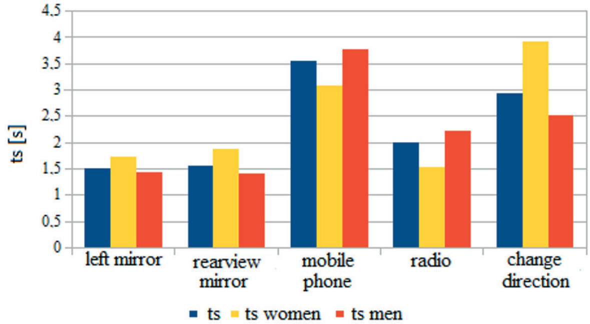

Fig. 2. Static test results

4.2. Research in motion and their results

During the tests in motion, the method of observing the surroundings during the manoeuvres of changing the direction of movement to the left was analysed. The time of "distraction" was determined on the basis of the analysis of the time of focusing attention on the left side mirror. The parameter taken into account during the study was also the number of glances in this direction. The research group consisted of 5 people aged 23–25 (two women, three men). Each person had a category B driving license and, according to the statement, had no visual impairments. The task of the tested people was to drive the designated route, on which there were places where the person supervising the tests (located inside the vehicle) ordered the manoeuvres in advance. The study was conducted in the parking lot of the Arena Lublin stadium in Lublin. The car was moving along the alleys, between the parking spaces. During the tests, other vehicles were also moving in the parking lot. An example of the route is marked with a green line in Figure 3. The number "1" marks the start and end of the ride, the numbers "2–5" mark the places where the left turn was made. The test persons covered the given route twice. Thus, eight measurements were collected for each person.

Fig. 3. The route of the car during the research (satellite image from the website www.google.pl)

https://doi.org/10.14669/AM/157645

Before the start of the movement tests, each driver adjusted the seat and mirror settings – in accordance with the applicable requirements. In order to approximate the course of the tests to real traffic conditions, the test person was obliged to interpret the situation behind the car. For this purpose, a red light emitting diode was placed on the left side of the test vehicle, behind the driver's seat. The task of the tested person was to observe the indications of the diode in the left side mirror – before starting the manoeuvre. The operation of the diode was controlled by the person supervising the research, who took a seat on the back seat. The ability to perform a manoeuvres was conditioned by the operating mode of the diode: if it emitted a red light, the manoeuvres was not allowed. If the light was not emitted, the manoeuvres could be performed. If the tested person, despite the signal sent by the supervisor, made a manoeuvres, it was treated as a driver's error and interpreted as the occurrence of a collision situation, which was to be recorded in the measurement sheet. During the tests, the behaviour of drivers in which, despite the signal prohibiting the execution of the manoeuvres, the manoeuvres was carried out was not recorded.

During the tests, the manoeuvres time ts was determined (from the moment of switching on the direction indicator to the moment of starting to turn the steering wheel). It was noticed that while preparing to perform the planned manoeuvres, the subjects looked at the side mirror several times. For each of these looks, one distinctly longer look could be identified. Its value is marked as t_{zl_max}. The time of single glances in the mirror was marked as t_{zl}. The number of glances made during the preparation for the n manoeuvres was also analysed. The results of time measurements for individual persons, the values of the average measured values and the standard deviation are presented in Table 2. The persons marked as "1" and "2" were women. People labelled "3", "4" and "5" are men. Table 3 summarizes the test results for all test subjects.

Tab. 2. Time of performing activities related to the left turn manoeuvres during road tests

	Average values over four left-turn maneuvers		Maximum time looking in the side mirror	Standard deviation			Average value of the number of looks in the mirror
Person	t_{s_m} [s]	Σt_{zl_m} [s]	t_{zl_max} [s]	σ_{tzl} [s]	$\sigma_{\Sigma tzl}$ [s]	σ_{tzl_max} [s]	n_m
1	5.9	2.2	0.9	0.26	0.6	0.2	4
2	4.2	2.2	1.4	0.68	1.2	0.8	2
3	6.5	2.7	0.8	0.26	1.1	0.4	5
4	4.8	1.9	1.1	0.44	0.6	0.5	3
5	4.1	2.4	1.2	0.63	1.0	0.6	4

Left turn manoeuvres time $t_{s\_m} = (4.1–6.5)$ s. The total time of observation of the surroundings in the left side mirror was in the range of (1.9–2.7) s, which consisted of 2–5 glances at the side mirror. A look that was clearly longer than the others lasted (0.8–1.4) s.

https://doi.org/10.14669/AM/157645

Tab. 3. Mean values from measurements of all persons

	Symbol	Value	Standard deviation σ [s]
Turning maneuver time	t_{ms} [s]	5.1	1.9
The longest time looking in the mirror	t_{zl_max} [s]	1.1	0.6
The total time of individual glances in the mirror	Σ_{tzl} [s]	2.3	1.0
Number of glances in the mirror	n	4	2
Time for a single look in the mirror	t_{zl} [s]	0.6	0.5

5. Analysis of research results, discussion

Analysing the influence of the conditions in which the tests were carried out, it can be seen that the specified time values during static tests were longer than those obtained during tests in motion. The method of conducting observations by the subjects was also different. People preparing for a simulated left-turn manoeuvres at a standstill focused their attention outside the field in front of the vehicle for an average time of $t_{sl} = 2.95$ s. In the case of this value, there was a discrepancy between the extreme values obtained, which is indicated by the value of the standard deviation $\sigma = 1.05$ s. During the standstill, it was also observed that after diverting attention from the area in front of the vehicle, the eyes were focused on the "other" areas until complete assurance of the ability to perform the manoeuvres was made.

During the movement test, the drivers looked several times in the mirror and ahead. The average number of glances in the mirror before starting the manoeuvres to change the direction of movement was equal to $n = 4$. During the movement test, the tested person, in addition to the task of performing the manoeuvres and making sure that it was possible to perform it, was required to adjust the speed, change gears and control the distance to the place of the manoeuvres. The total time of checking in the side mirror during the dynamic test was 0.78 s (2.3–1.52) longer than the observation time in the static test. The average value of the longest look in the left mirror (which can be interpreted as allowing to determine and recognize the situation – unlike the others, which "only" could monitor changes in the recognized state of affairs) was equal to 1.1 s. Compared to the average time of looking in the side mirror during the static test (1.52 s), it was 0.4 s shorter.

Women and men participated in the research. The size of the research group does not allow for the formulation of categorical conclusions regarding the method of conducting observations depending on gender, however, the obtained results may be a premise regarding the behaviour of women and men, and be an indication for further work of this type. Analysing the obtained data, it can be concluded that during the static test, men (people marked with numbers 4–10) conducted observations in mirrors in a shorter time than women (people marked with numbers 1–3). Attention time while changing the radio station and checking the current time on the mobile phone was longer in the group of men than in the group of

https://doi.org/10.14669/AM/157645

women. During the movement test, in the case of a group of women, it was also observed that the average value of the longest gaze time in the side mirror and the average value of the time of other gazes was greater than in the case of men (by approx. (0.1–0.2) s).

During the movement test, the subjects performed the manoeuvres in an average time of 5.1 s. The total time of looking in the side mirror was on average 2.3 s, which is about 45% of the duration of the manoeuvres. The average longest time of checking in the mirror was equal to 1.1 s (22% of the manoeuvres time), and the average value of the time of a single glance was equal to 0.6 s (12% of the manoeuvres time). During the manoeuvre, the subjects looked in the mirror 4 times on average, which indicates that during the manoeuvres there were 4 periods of "breaks", lasting approx. 0.7 s (each), in which the observation was not carried out. Such a way of conducting observations and the time values determined during the tests may be of significant importance for the analysis of the course of accidents involving a collision of vehicles, in which the driver of one performs a change of direction and the other performs an overtaking manoeuvres. This problem becomes particularly important when the overtaking vehicle moves dynamically and at a much higher speed, or when a column of vehicles is overtaken with a car turning left at the front. Road accidents of this type occur quite often, and an increase in their number is observed in the spring and summer, when a significant number of two-wheeled vehicles are on the road. According to the authors, for situations in which – by definition – the driver's attention should be dispersed and focused on many areas at the same time, the reaction time may be extended by at least the value of the "break" time in observing the surroundings in the mirrors.

6. Conclusion

The specified values of the time of focusing the attention of drivers on activities other than observing the road environment in front of the vehicle indicate that the adoption of the reaction time value in the analysis of the course of the accident based on literature data [41] should be preceded by an analysis of the way the driver observes the environment. This is especially true for manoeuvres in relation to which legal regulations [42] impose obligations on them, forcing them to conduct observations in many areas – simultaneously. The research results indicate that the time of focusing attention on an area other than the one in front of the vehicle is not shorter than 1 s, and observing the surroundings in the side mirror (while driving) is related to looking into this area several times for a short time. In the practice of giving opinions on the course of road accidents, it seems reasonable to assume at least the value of the reaction time close to the upper limit of the time intervals specified in [41]. In special cases, even with "careful" observation of the road situation as part of the obligation to exercise extreme caution, a dangerous situation arising in the area visible in the vehicle's mirrors can be recognized in time appropriate for the so-called "unexpected situational stimulus". A separate issue is the examination of the ability to interpret the road situation and its changes on the basis of a series of short-term observations in the side and rear-view mirrors. This problem may be of particular importance in the case of frequent road accidents involving a collision of vehicles, in which one of the drivers performs a left-turn manoeuvres and the other (fast-moving) overtakes a column of vehicles.

https://doi.org/10.14669/AM/157645

7. References

[1] Ágoston G., Madlenák R.: Road safety macro assessment model: Case study for Hungary. Periodica Polytechnica Transportation Engineering. 2021, 49(1), 89–92 DOI: 10.3311/PPtr.13083.

[2] Cernicky L., Kalasova A.: The application of telematic technologies in Slovakia – the possibility of improving road safety in the Slovak Republic. Scientific Journal of Silesian University of Technology-Series Transport. 2015, 86, 5–11.

[3] Čulík K., Kalašová A., Štefancová V.: Evaluation of driver's reaction time measured in driving simulator. Sensors. 2022, 22(9), 3542, DOI: 10.3390/s22093542.

[4] Dhananjay A., Mote S., Prajapati S., Chacharkar P., Rana N., Vispute V.: To Analyze Reaction Time of Drivers Based on Drivers Characteristics- A Review. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE). 2017, 14(2), 16–18, DOI: 10.9790/1684-1402041618.

[5] Droździel P., Krzywonos L., Madlenak R., Rybicka I.: Selected aspects of analyses of failure rates of active safety systems in buses. Communications-Scientific Letters of the University of Žilina. 2014, 16(3), 114–119.

[6] Droździel P., Tarkowski S., Rybicka I., Wrona R. Drivers' reaction time research in the conditions in the real traffic. Open Engineering. 2020, 10(1), 35–47, DOI: 10.1515/eng-2020-0004.

[7] Droździel P., Wrona R.: Legal and utility problems of accidents on express roads and motorways. 11th International Science and Technical Conference Automotive Safety. Casta, Slovakia. 2018, 1–5, DOI: 10.1109/AUTOSAFE.2018.8373315.

[8] Egaji O.A., Chakhar S., Brown D.: An innovative decision rule approach to tyre pressure monitoring. Expert Systems with Applications. 2019, 124, 252–270, DOI: 10.1016/j.eswa.2019.01.051.

[9] Erd A., Jaśkiewicz M., Koralewski G., Rutkowski D., Stokłosa J.: Experimental research of effectiveness of brakes in passenger cars under selected conditions. 11th International Science and Technical Conference Automotive Safety, 2018, 1–5, DOI: 10.1109/AUTOSAFE.2018.8373299.

[10] Ghadi M., Torok A., Tanczos K.: Study of the economic cost of road accidents in Jordan. Periodica Polytechnica Transportation Engineering. 2018, 46(3), 129–134, DOI: 10.3311/PPtr.10392.

[11] Gogola M., Hocova M.: Deurbanisation and mobility. 6th Transport Research Arena (TRA), Transportation Research Procedia. 2016, 14, 1193–1200, DOI: 10.1016/j.trpro.2016.05.190.

[12] Gosławski Ł., Kubiak P., Mrowicki A., Soghabatyan T., Sys E., Wang Y-W., Zou T.: Analysis of braking marks left by vehicles equipped with ABS with IR spectroscopy. The Archives of Automotive Engineering – Archiwum Motoryzacji. 2019, 84(2), 33–43, DOI: 10.14669/AM.VOL84.ART3.

[13] Green M.: How long does it take to stop? Methodological analysis of driver perception-brake times. Transportation Human Factors. 2000, 2(3), 195–216.

[14] Grencik J., Ruman F.: Proposal of new maintenance scheme of air brake system on semi-trailer combination. Diagnostyka. 2015, 16(2), 11–19.

[15] Guzek M.: Driver's reaction time in the context of an accident in road traffic. Advances in Intelligent Systems and Computing. 2020, 1032, 184–193, DOI: 10.1007/978-3-030-27687-4_19.

[16] Hudak M., Madlenak R.: The research of driver distraction by visual smog on selected road stretch in Slovakia. Procedia Engineering. 2017, 178, 472–479, DOI: 10.1016/j.proeng.2017.01.090.

[17] Hurtova I., Sejkorova M., Verner J., Kucera M.: Preference and area coordination of public transport in modern city. Engineering for Rural Development. 2018, 17, 2085–2091.

[18] Jurecki R., Stańczyk T., Jaśkiewicz M.: Driver's reaction time in a simulated, complex road incident. Transport. 2017, 32(1), 44–45, DOI: 10.3846/16484142.2014.913535.

[19] Jurecki R., Stańczyk T.: The test methods and the reaction time of drivers. Eksploatacja i Niezawodność. 2011, 51(3), 84–91.

[20] Kalasova A., Mikulski J., Kubikova A.: The impact of intelligent transport systems on an accident rate of the chosen part of road communication network in the Slovak Republic. Communications in Computer and Information Science. 2016, 640, 47–58, DOI: 10.1007/978-3-319-49646-7_5.

[21] Kampf R., Stopka O., Kubasakova I., Zitricky V.: Macroeconomic evaluation of projects regarding the traffic constructions and equipment. Procedia Engineering. 2016, 161, 1538–1544, DOI: 10.1016/j.proeng.2016.08.623.

[22] Kucmin T., Kucmin A., Turska D., Turski A., Nogalski A.: Coping styles and dispositional optimism as predictors of post-traumatic stress disorder (PTSD) symptoms intensity in paramedics. Psychiatria Polska. 2018, 52(3), 557–571, DOI: 10.12740/PP/68514.

[23] Kulkarni A., Nanaware R., Kulkarni A., Garud V.: Synthesis and optimization of steering mechanism of extralong semi-trailer vehicle. Procedia Structural Integrity. 2019, 14, 158–167, DOI: 10.1016/j.prostr.2019.05.021.

[24] Macioszek E., Kurek A.: A case study analysis of roundabouts entry capacity localised on one of the main road in Sosnowiec city (Poland). Scientific Journal of Silesian University of Technology. Series Transport. 2019, 105, 139–156, DOI: 10.20858/sjsutst.2019.105.12.

[25] Madlenak R., Hudak M.: The research of visual pollution of road infrastructure in Slovakia. Communications in Computer and Information Science. 2016, 640, 415–425, DOI: 10.1007/978-3-319-49646-7_35.

[26] Mamcarz P., Droździel P., Madleňáková L., Sieradzki A., Droździel P.: Level of occupational stress, personality and traffic incidents: Comparative study of public and freight transport drivers. Transportation Research Procedia. 2019, 40, 1453–1458, DOI: 10.1016/j.trpro.2019.07.201.

[27] Matijosius J., Ciziuniene K., Petraska A., Sokolovskij E.: The comparison of the accident rates in heavy transport sectors of Europe and USA. Proceedings of the 3rd International Conference on Traffic and Transport Engineering (ICTTE), Belgrade, Serbia, 2016, 1097–1101.

[28] Matuszak Z., Nowak A., Zabinska I., Martinez de Oses F.X.: Road safety on the example of the city of Bytom. The Archives of Automotive Engineering — Archiwum Motoryzacji. 2019, 83(1), 43–57, DOI: 10.14669/AM.VOL83.ART3.

[29] McGehee D.V., Mazzae E.N., Baldwin G.H.S.: Driver reaction time in crash avoidance research: validation of a driving simulator study on a test track. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 2000, 44(20), 3–320, DOI: 10.1177/154193120004402026.

[30] Mensing F., Bideaux E., Trigui R., Tattegrain H.: Trajectory optimization for eco-driving taking into account traffic constraints. Transportation Research Part D: Transport and Environment. 2013, 18(1), 55–61, DOI: 10.1016/j.trd.2012.10.003.

[31] Orynycz O., Tucki K., Wasiak A., Sobótka R., Gola A.: Evaluation of the brake's performance dependence upon technical condition of car tires as a factor of road safety management. Energies. 2020, 13(1), 9, DOI: 10.3390/en13010009.

[32] Pawar N., Velaga N.: Modelling the influence of time pressure on reaction time of drivers. Transportation Research Part F: Traffic Psychology and Behaviour. 2020, 72, 1–22, DOI: 10.1016/j.trf.2020.04.017.

[33] Poliak M., Mrnikova M., Simurkova P., Medvid P., Poliakova A., Hernandez S.: Social law in road transport like tool safety road transport. 11th International Science-Technical Conference Automotive Safety, Casta, Slovakia, 2018, 1–7, DOI: 10.1109/AUTOSAFE.2018.8373317.

[34] Rievaj V., Vrabel J., Hudak A.: Tire inflation pressure influence on a vehicle stopping distances. International Journal of Traffic and Transportation Engineering. 2013, 2(2), 9–13, DOI: 10.5923/j.ijtte.20130202.01.

[35] Rybicka I., Drozdziel P., Stopka O., Luptak V.: Methodology to propose a regional transport organization within specific integrated transport system: a case study. Transport Problems. 2018, 13(4), 115–125, DOI: 10.20858/tp.2018.13.4.11.

[36] Samociuk W., Krzysiak Z., Bukova B., Brumercikova E., Bąkowski H., Krzywonos L.: Analysis of international transport of chemical products in the countries of the Visegrad Group. Przemysł Chemiczny. 2018, 97(6), 829–833, DOI: 10.15199/62.2018.6.2.

https://doi.org/10.14669/AM/157645

[37] Skrucany T., Harantova V., Kendra M., Barta D.: Reducing energy consumption by passenger car with using of non-electrical hybrid drive technology. Advances in Science and Technology Research Journal. 2017, 11(1), 166–172, DOI: 10.12913/22998624/66505.

[38] Stopka O., Simkova I., Konećny V.: The quality of service in the public transport and shipping industry. Naše More. 2015, 62(3), 126–130, DOI: 10.17818/NM/2015/SI7.

[39] Svetina M.: The reaction times of drivers aged 20 to 80 during a divided attention driving. Traffic Injury Prevention. 2016, 17(8), 810–814, DOI: 10.1080/15389588.2016.1157590.

[40] Šarkan B., Semanova,S., Harantova V., Stopka O., Chovancova M., Szala M.: Vehicle fuel consumption prediction based on the data record obtained from an engine control unit. III International Conference of Computational Methods in Engineering Science (CMES'18), Kazimierz Dolny, Poland, 2018. MATEC Web of Conferences. 2019, 252, 06009, 1–4, DOI: 10.1051/matecconf/201925206009.

[41] Unarski J.: Czas reakcji kierowców – standardy a rzeczywistość. Paragraf na drodze. 1999, 6–7, Instytut Ekspertyz Sądowych, Kraków.

[42] Ustawa z dnia 20 czerwca 1997 r. Prawo o ruchu drogowym. Dz. U. 1997 nr 98 poz. 602.

[43] Vrabel J., Sarkan B., Vashisth A.: Change of driver's reaction time depending on the amount of alcohol consumed by the driver – the case study. The Archives of Automotive Engineering – Archiwum Motoryzacji. 2020, 87(1), 47–56, DOI: 10.14669/AM.VOL87.ART4.

[44] Wen T.H., Chin W.C.B., Lai P.C.: Understanding the topological characteristics and flow omplexity of urban traffic congestion. Physica A: Statistical Mechanics and its Applications. 2017, 473, 166–177, DOI: 10.1016/j.physa.2017.01.035.

[45] Zhuk M., Kovalyshyn V., Royko Y., Barvinska K.: Research on drivers' reaction time in different conditions. Eastern-European Journal of Enterprise Technologies. 2017, 2(3–86), 24–31, DOI: 10.15587/1729-4061.2017.98103.

[46] Žuraulis V., Nagurnas S., Pečeliūnas R., Pumputis R., Skačkauskas P.: The analysis of drivers' reaction time using cell phone in the case of vehicle stabilization task. International Journal of Occupational Medicine and Environmental Health. 2018, 31(5), 633–648, DOI: 10.13075/ijomeh.1896.01264.